Fermilab

DATA ON SATURATION EFFECTS IN THE SAVER DIPOLES

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August 12, 1982

I

A memo addressed to Al McInturff was sent by me on December 3, 1980 requesting an analysis of the data on the integrated field $\int B \cdot d\ell$ beyond $\sim$4kA. It was felt at the time that several corrections were needed to get the true picture of the dipole field saturation from the measurement data. McInturff responded to my request on December 16. He analyzed data on seventeen magnets and his analysis included effects from mechanical distortion, harmonic components and magnetization. Results from his analysis on the saturation are reproduced in Table 1.*

Table 1 - Transfer Function Corrections due to "Fe" Saturation. Correction applied to transfer functions determined by fixing "L" = 6.112m.

Typical run to run variation ±0.015%; shape error variation (above 2.75kA) ±.005%.

2750A	0.000%	3600A	0.021%	4100A	0.065%
3000A	0.004	3750A	0.031	4200A	0.082
3250A	0.009	3900A	0.044	4300A	0.101
3500A	0.017	4000A	0.053	4400A	0.125
				4500A	0.154

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* Memo from A. McInturff to S. Ohnuma, December 16, 1980.

Because of other, more pressing projects, *McInturff could not finish
a report on his work which would have included a complete analysis
of many more magnets.* Although he intends to issue such a report in
the near future, it may be worthwhile to review the existing data
now; more than eighty dipoles have been measured beyond 4kA so far.

This report was of course never meant to be a substitute for the
one by McInturff. For one thing, it is simply a compilation of the
raw data without any corrections. On the other hand, since McInturff
has shown that the corrections are all small when one compares the
value of $\int B \cdot d\ell$ above 4kA <u>relative</u> to the value at 3kA, the conclusion
on the beam momentum as a function of the excitation current above
~ 900 GeV/c and ~ 4 kA should hold even after all corrections are
taken into account.

<h2 style="text-align:center">II</h2>

The last measurement of $\int B \cdot d\ell$ above 4kA in 1981 was done for
TB828 on 12/17/81 at 4.1 and 4.2kA. Recently, Bruce Brown has re-
sumed the data taking with four dipoles in July,

TC648	7/21/82	4.1 to 4.4kA,
TC650	7/21/82	4.1 to 4.5kA,
TB689	7/28/82	4.1 to 4.5kA,
TB702	7/27/82	4.1 to 4.4kA.

Altogether, data are now available for

3 dipoles at 4.5kA,	11 dipoles at 4.4kA,
22 dipoles at 4.3kA,	64 dipoles at 4.2kA,
83 dipoles at 4.1kA.	

Data for individual magnets at 4.3, 4.4 and 4.5kA are listed in
Table 2. The statistics for the data at 4.2 and 4.1kA are:

4.2kA	$R = 0.999225$, $\sigma = .000061$,
4.1kA	$R = 0.999383$, $\sigma = .000076$

where

$$R = \int B \cdot d\ell \; /(\text{excitation current}) \quad \underline{\text{relative to the 3kA value}}$$

and σ is its standard deviation.

Table 2. $\int B \cdot d\ell/I$ relative to the 3kA value

1. <u>I = 4.5 kA</u>

#421	11/22/80	.998515	#650	7/21/82	.998323
#689	7/28/82	.998325			

2. <u>I = 4.4kA</u>

#416	3/26/81	.998795	#421	11/22/80	.998793
#434	4/01/81	.998835	#437	1/09/81	.998809
#447	4/20/81	.998854	#464	5/26/81	.998733
#539	5/24/81	.998675	#648	7/21/82	.998663
#650	7/21/82	.998644	#689	7/28/82	.998679
#702	7/27/82	.998718			

3. <u>I = 4.3kA</u>

#343	8/21/80	.998949	#347	12/17/80	.999048
#367	1/07/81	.998930	#384	9/03/81	.999010
#408	3/31/81	.998976	#416	3/26/81	.999045
#421	11/22/80	.999020	#434	4/01/81	.999066
#437	1/09/81	.999046	#438	12/22/80	.999033
#445	2/24/81	.999031	#447	4/20/81	.999079
#454	1/23/81	.998961	#464	5/26/81	.998984
#495	3/08/81	.999051	#507	7/22/81	.998821
#539	5/24/81	.998956	#566	6/14/81	.999027
#648	7/21/82	.998907	#650	7/21/82	.998882
#689	7/28/82	.998895	#702	7/27/82	.998964

Using the data at 4.2, 4.3, 4.4 and 4.5kA, one finds

$$R \equiv 1. - \Delta,$$

$$\Delta = 0.284 \times 10^{-7+1.057*I} \; ; \quad I = \text{excitation current in kA.}$$

This is shown in Fig. 1 together with some data. From Table 2, one
sees that the measurements made in July of this year show a slightly
larger amount of saturation. However, more data are needed before

one can draw any reliable conclusion.

III

So far, more than 700 dipoles have been measured at least up to 4kA and 415 are already either installed or assigned in the tunnel. From these available data, it seems safe to say that

$$\int B \cdot d\ell/I \text{ at } I = 3kA = (61.07 \sim 61.10) \text{ kG-m/kA}.$$

The expected momentum of the beam as a function of the dipole excitation current is shown in Fig. 2. The relation should be good to within ±500 MeV/c.

FIG. 1

Saturation Effects, Energy Saver Dipoles.
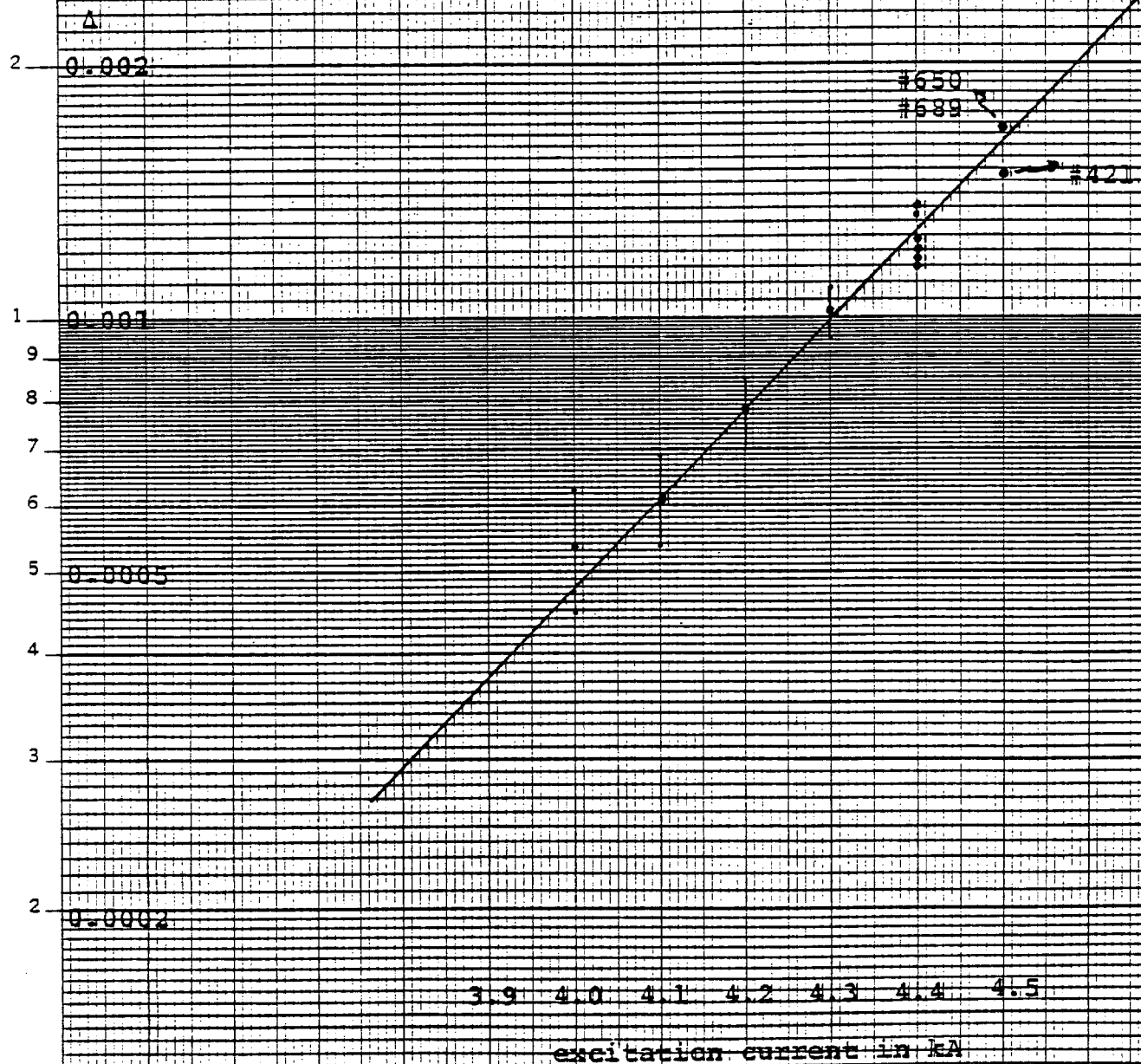
Integrated field relative to the value at 3 kA.

$\int B \cdot d\ell \ (I \ kA) = (I/3) \times (1. - \Delta) \times \int B \cdot d\ell \ at \ 3 \ kA.$

For $I \geq 4 \ kA$, $\Delta = 0.284 \ 10^{-7+1.057*I}.$

Δ

0.002

#650
#689

#421

0.001

0.0005

0.0002

3.9   4.0   4.1   4.2   4.3   4.4   4.5

excitation current in kA

FIG. 2

p(TeV/c)

Momentum vs Excitation Current

The excitation current corresponding
to 1.00 TeV/c is expected to be
4.44 kA.

Below 4.46kA,

p in GeV/c = 225.6*I in kA.

excitation current in kA